



# **Efforts Toward Development Of A High Resolution Global Climatology Of Overshooting Cloud Top Detections Using MODIS and Geostationary Satellite Imager Data**

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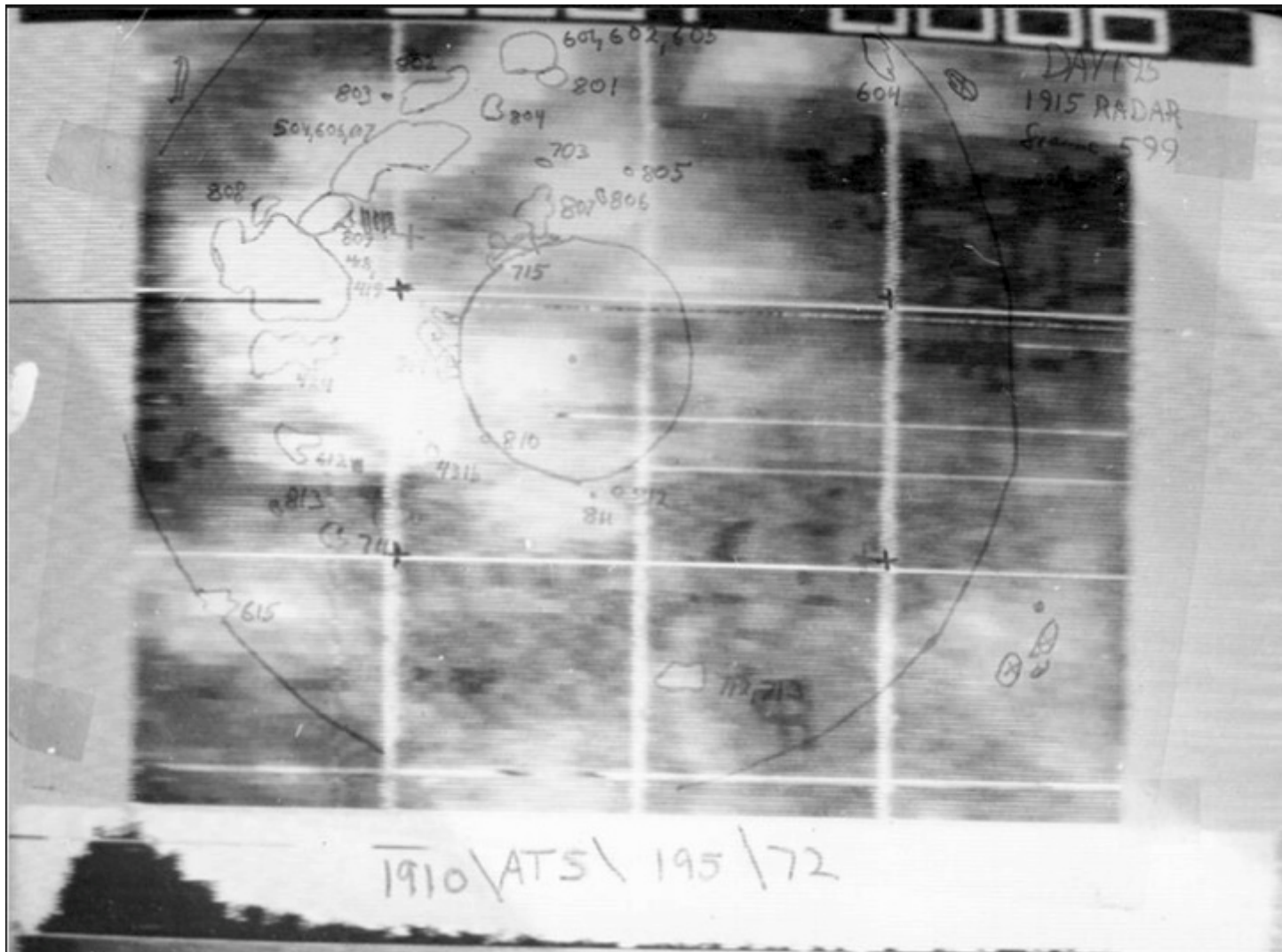
**Konstantin Khlopenkov**

*Science Systems and Applications, Inc*

# State-Of-The-Art Overshooting Cloud Top Analyses (circa 1972)



- ATS-1 satellite imagery with hand contoured radar echoes taped to a monitor, 13 July 1972



**Overshooting Top**

**Above-Anvil Cirrus Plume**  
Detrainment Of Ice From The OT Region

**Anvil**

**Updraft**

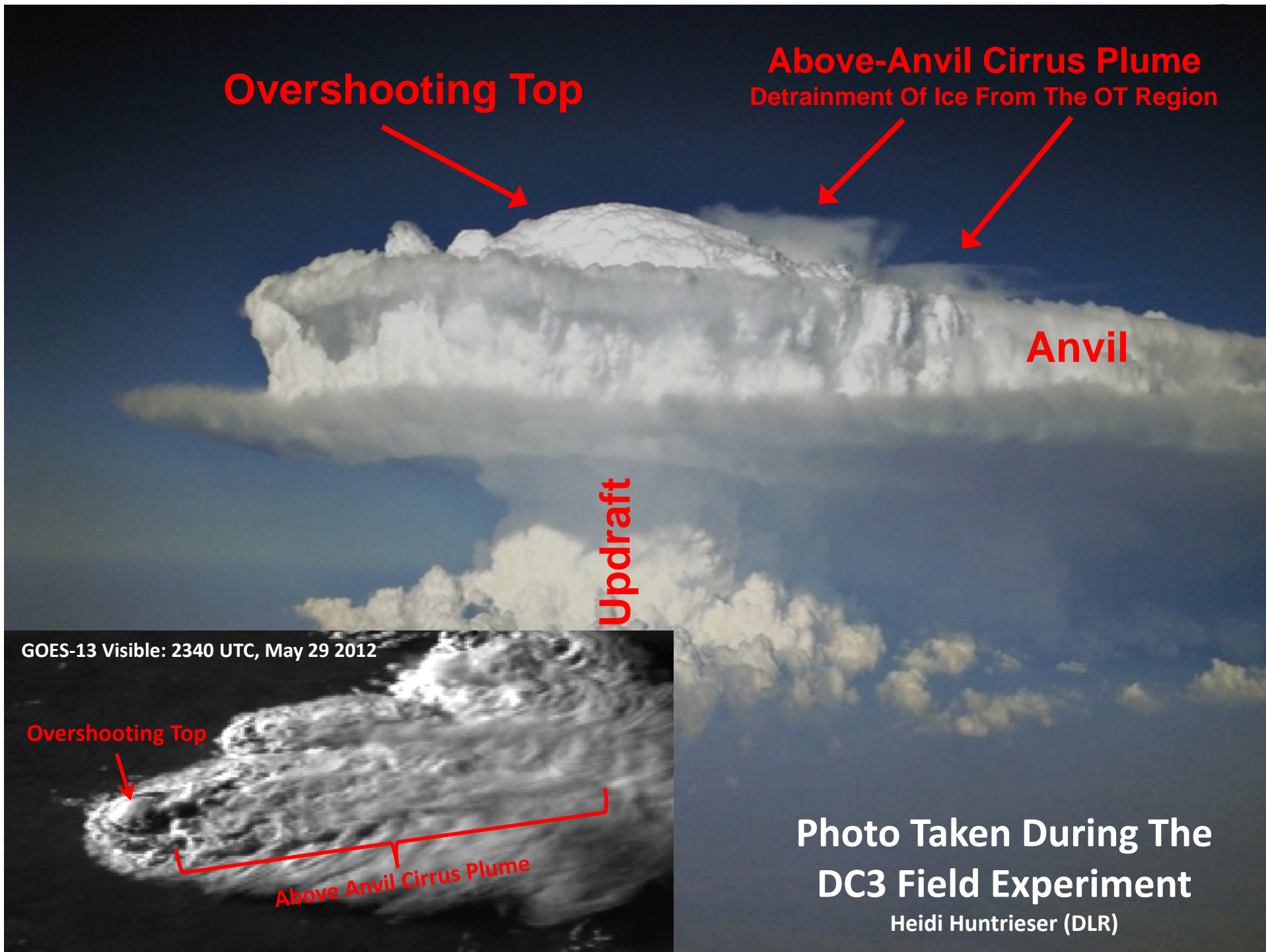
GOES-13 Visible: 2340 UTC, May 29 2012

**Overshooting Top**

**Above Anvil Cirrus Plume**

**Photo Taken During The  
DC3 Field Experiment**

Heidi Huntrieser (DLR)



# What Do I Consider To Be An Overshooting Top?



## IR + Visible "Sandwich Product"

Setvak et al. (*Atmos Res.*, 2013)

Shadowing induced by height differential between OT and primary anvil

Warm and differently textured pixels corresponding to cirrus detrainment in lower stratosphere

Small region of anomalously cold and highly textured pixels within an Overshooting Top (OT)

Courtesy of Martin Setvak (Czech Hydrometeorological Institute)

BT 240 K | 200 K

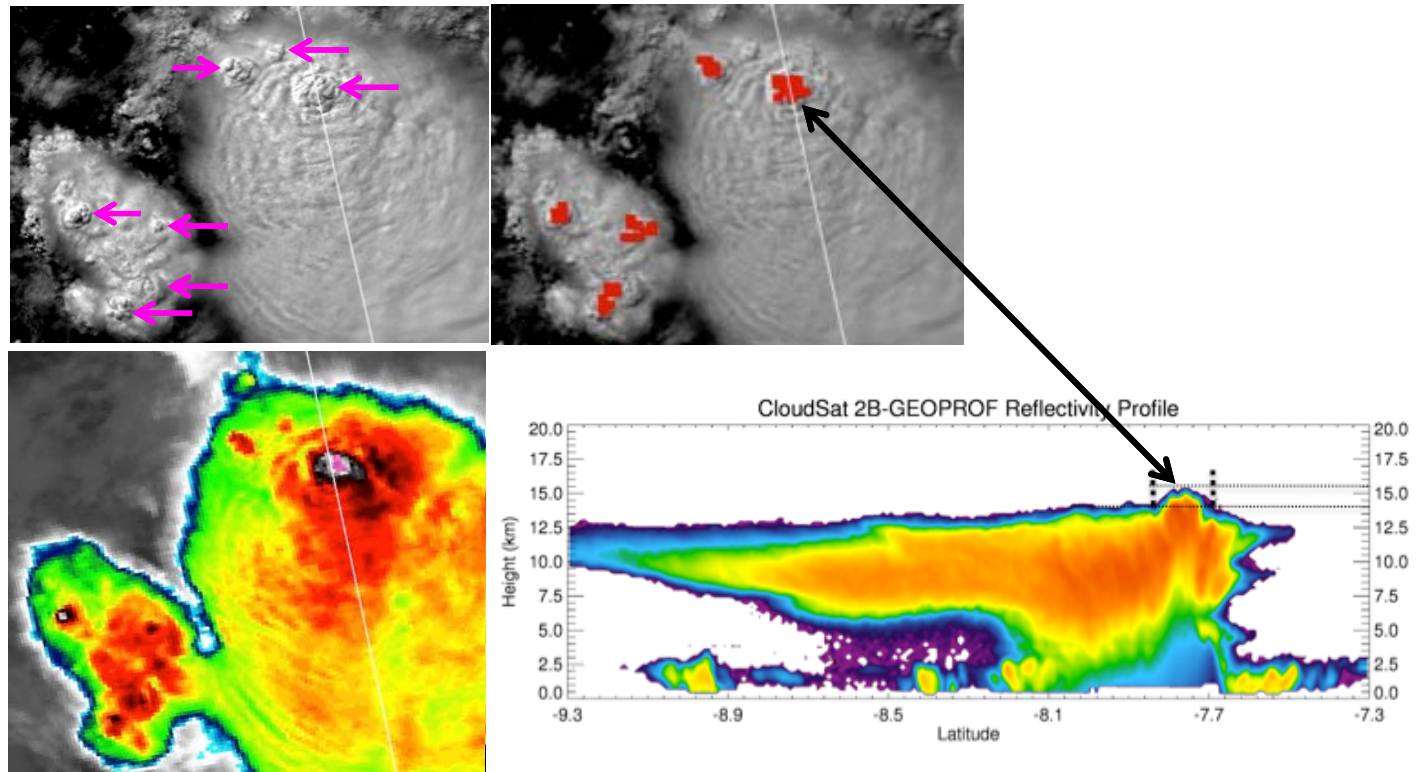
2009-07-09 11:35 UTC NOAA 15 (South Dakota, Minnesota, Nebraska, Iowa, U.S.A.)

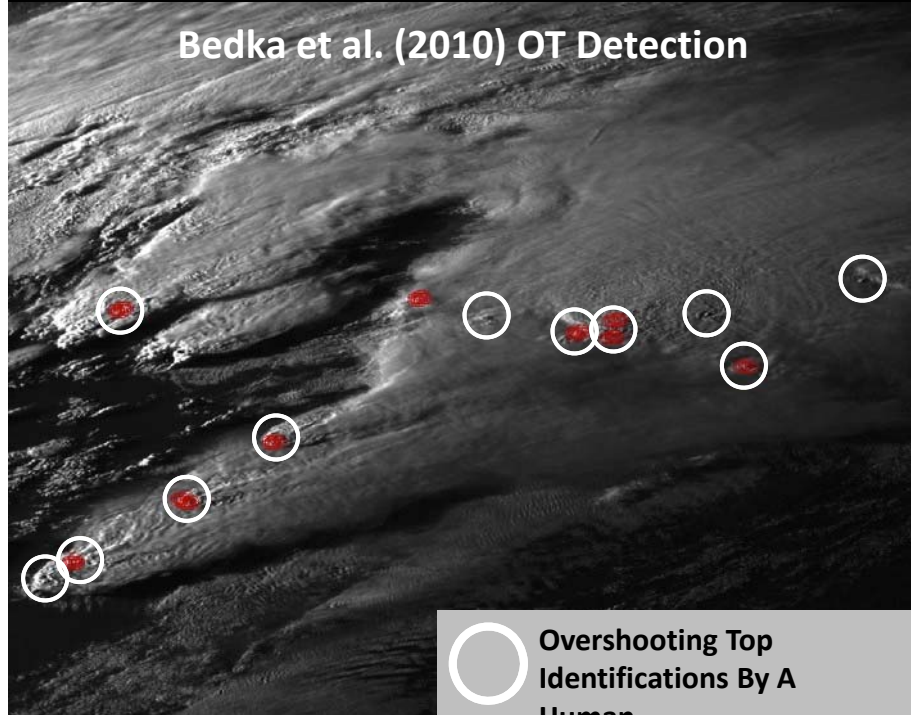
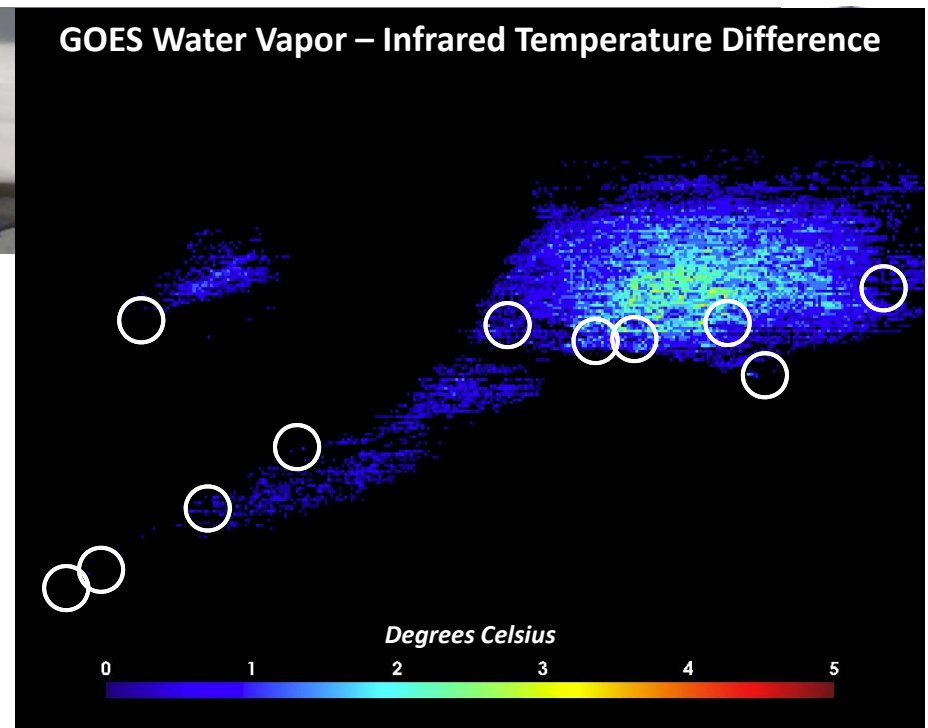
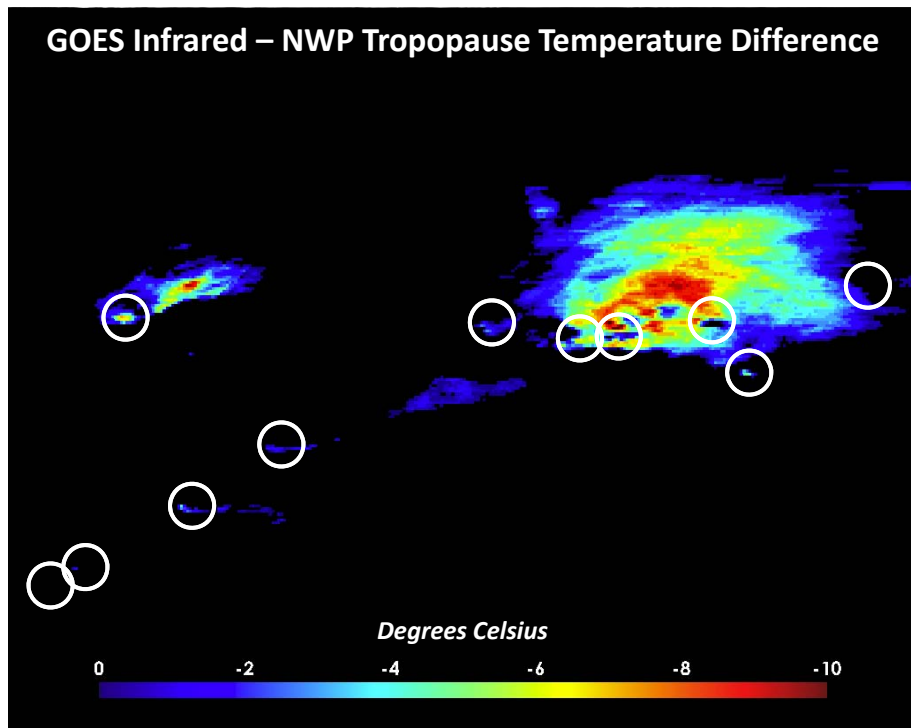
# Bedka et al. (2010) IR-Based Overshooting Cloud Top Detection



- Hazardous and UTLS-penetrating convective storms typically have one or more overshooting top (OT) regions
- A satellite-based OT detection method was funded by the NASA Applied Sciences Program and GOES-R ABI Aviation Algorithm Working Group for near real-time aviation safety and weather forecast applications (Bedka et al. 2010-2012)
- The method uses spatial analysis and thresholding of satellite IR temperature combined with NWP tropopause temperature to automatically identify individual OT regions

## MODIS 250 m Visible, 1 km IR, and Overshooting Cloud Top Detections





### Limitations of Current OT Detection Approaches

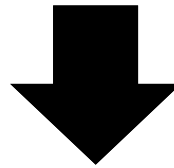
- **All approaches use fixed criteria for binary yes/no OT detection**
- Detection techniques that use WV signals identify large portions of the convective anvil and are incapable of isolating only OT regions
- Bedka et al (2010) is the only approach that uses spatial analysis of the anvil cloud for detection
- No approaches use the visible channel which typically provides the clearest indication of an OT based on texture and shadowing

# *Probabilistic Overshooting Cloud Top Detection*

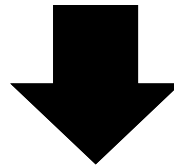


***GOAL: Mimic the human OT identification process using IR & visible satellite imagery and numerical weather analysis model data within an automated computer algorithm***

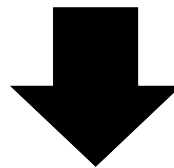
**Satellite IR and Visible OT Indicators Derived Via Image Pattern Recognition  
+ NWP Level of Neutral Buoyancy and Tropopause Temperature Fields**



**Large Training Database of Satellite + NWP Fields For Both OT and Non-OT Anvil Regions**



**Logistic Regression Model Used To Discriminate Between The OT and Non-OT Anvil Populations**

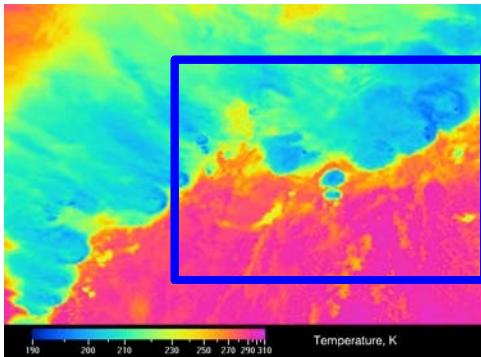


**OT Probability Product**

# IR-Based Pattern Recognition Analysis

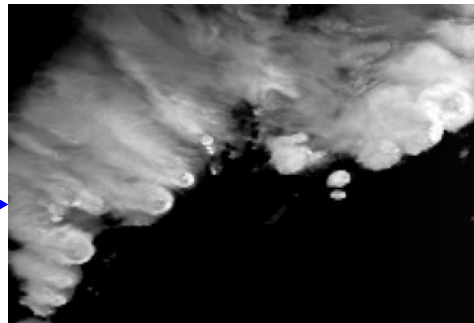


**Input MODIS IR  
Temperature (BT) Image,  
Resampled To 4 km/Pixel  
6 May 2007, 1925 UTC**

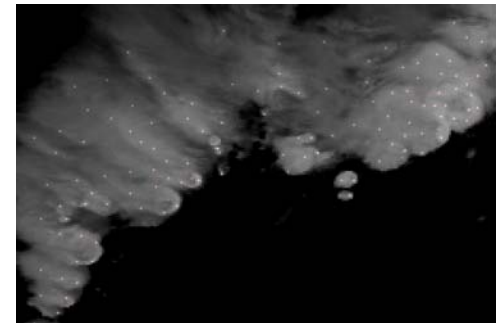


**BT Score:**  $BT_{score} = (T_{avg} - T)^{0.7} (255 - T)^{1.3} / 1600 + 2 \cdot \sigma(T)$

Used to eliminate need for a fixed BT threshold,  
enhance deep convection, and separate likely  
convective from non-convective clouds



**Identify Local BT Score Maxima  
As Initial OT Candidates**



**Perform Spatial Analysis  
Of The BT Score Field  
Around Initial OT Candidates  
To Map Convective Anvils**



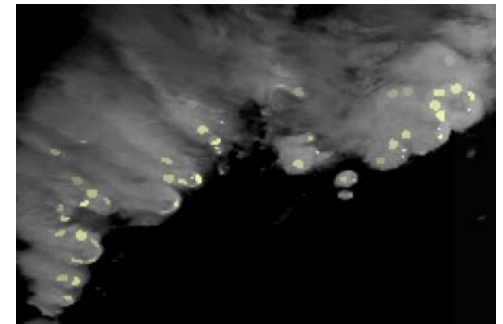
Pattern recognition used to ensure that the region being  
analyzed is within deep convection and 2) the feature of  
interest has a shape and prominence typical of OT regions

**Pattern recognition uses**

- OT shape correlation
- BT Score prominence relative to surrounding anvil
- Anvil flatness, roundness, and edge sharpness

**The net result is a cumulative rating obtained for each  
possible OT region. Pixels with a non-zero rating are  
considered final "OT Candidate" regions**

**Final OT Candidate Regions  
Based on IR Analysis**

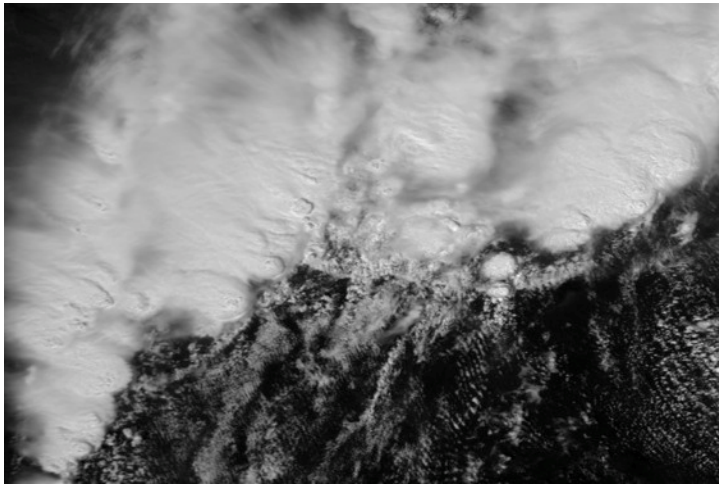


# Visible Channel Analysis

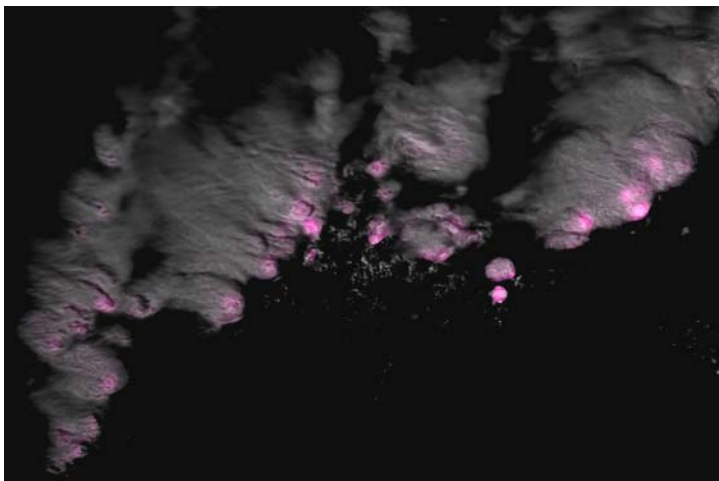


Use a combination of statistical, spectral, and spatial analyses to quantify the degree of “texture” and shadowing present in a visible image associated with OT regions and gravity waves

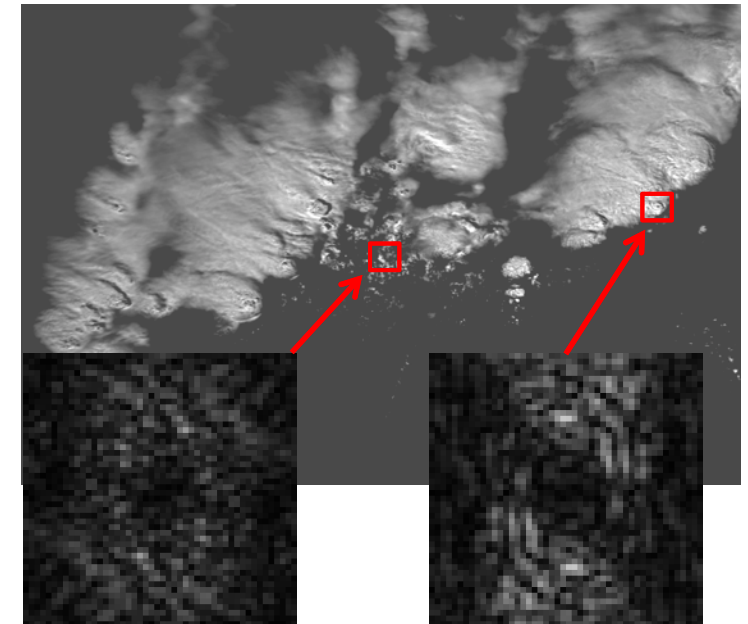
Input MODIS 1 km Visible Image



Final OT Candidate Regions  
Based on Visible Analysis



Statistical and Spectral Analysis To Identify Convective  
Anvils, OTs, and Nearby Gravity Waves



Fourier frequency  
spectrum of an area  
with random spatial  
variability.

No ring pattern in  
the spectrum

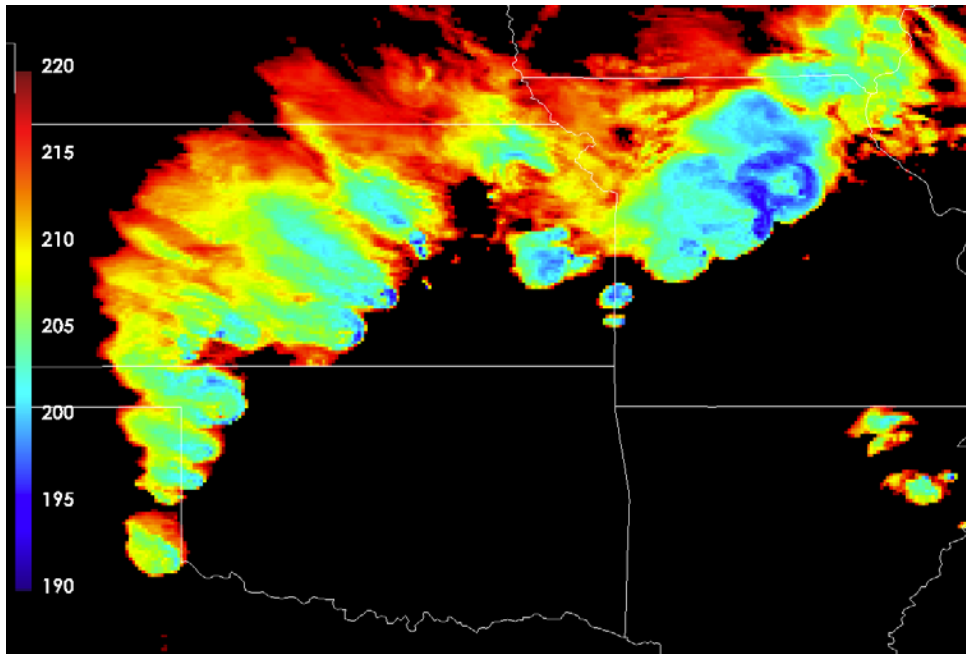
Fourier frequency  
spectrum of a typical  
OT region

Ring fragments in the  
spectrum can be  
identified

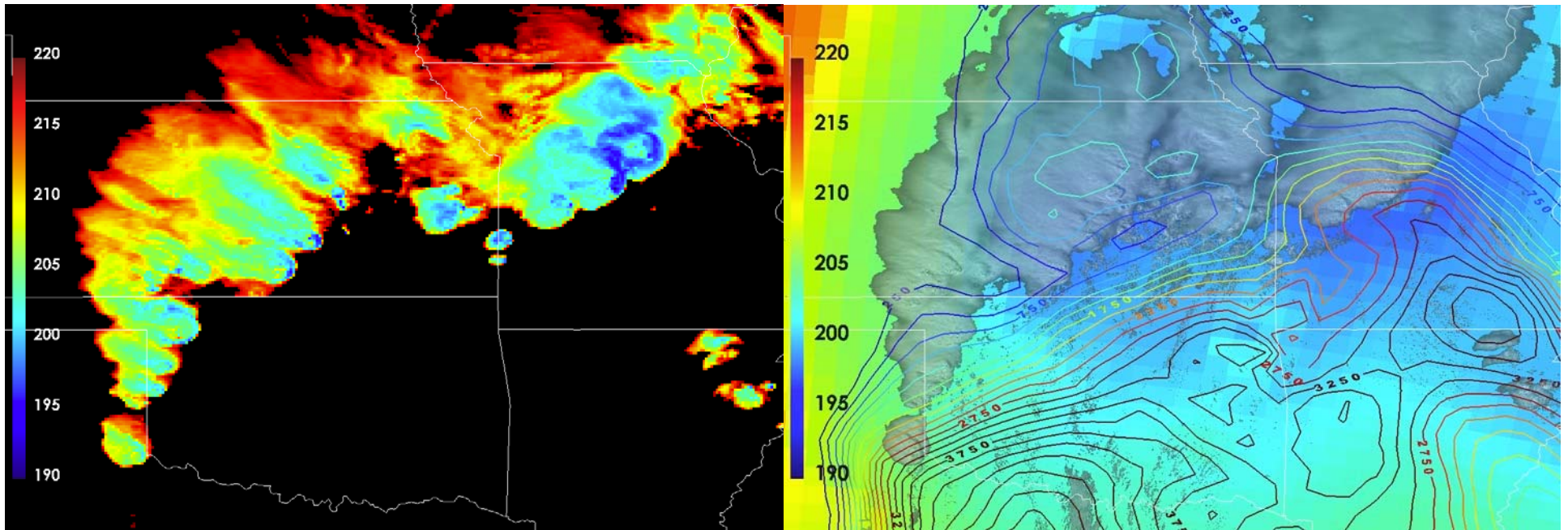


# *Infrared Comparisons With Reanalysis Model Fields*

Input MODIS Infrared Image



MODIS Visible Overlaid With  
NWP Tropopause Temp and CAPE Contours

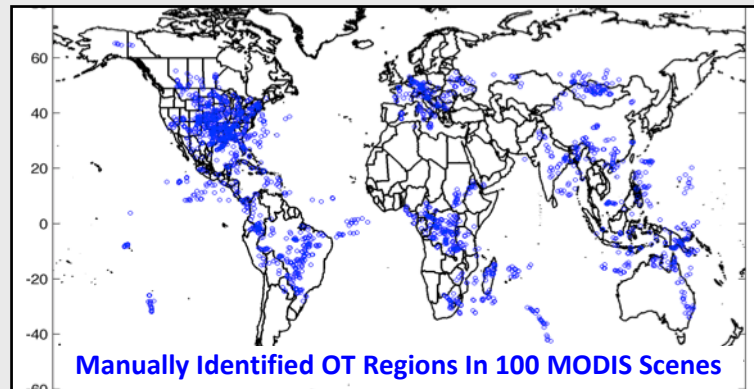


- A set of NWP-based parameters were evaluated for statistical significance in a logistic regression model
- The 1) Satellite Infrared – Tropopause Temperature and 2) Infrared – Most Unstable Level of Neutral Buoyancy Temperature difference fields were significant for OT discrimination at the 99+% confidence level

# Logistic Regression and Final OT Detection Product



A database of ~2000 OT events were manually identified in 100 daytime Aqua MODIS 250 m visible images. A similar number of non-OT anvil regions were also identified. This database is used to train and validate a logistic regression model to assign high detection probability to OT-like features

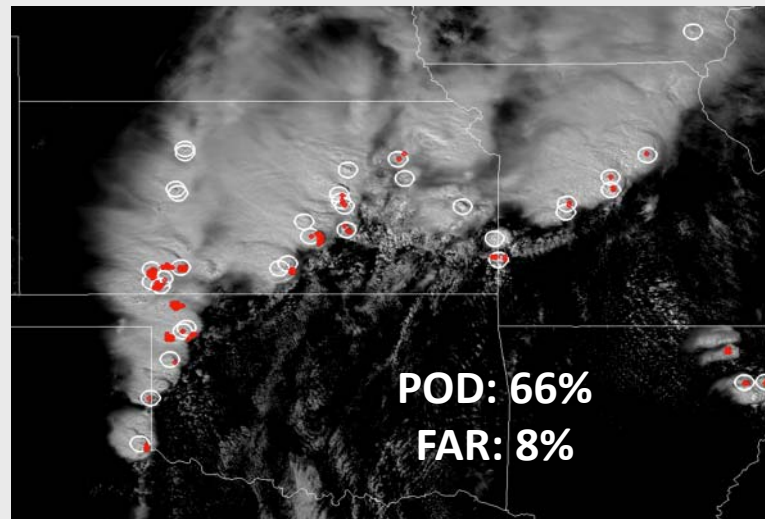


Manually Identified OT Regions In 100 MODIS Scenes

$$\text{Regression Result} = W_0 + W_1 * (\text{OT-Mean Anvil IR BT}) + W_2 * (\text{IR BT} - \text{Tropopause Temp}) \\ + W_3 * (\text{IR BT} - \text{MU LNB Temp})$$

$$\text{OT Probability} = \frac{1}{1 + \exp(-1 * \text{Regression Result})}$$

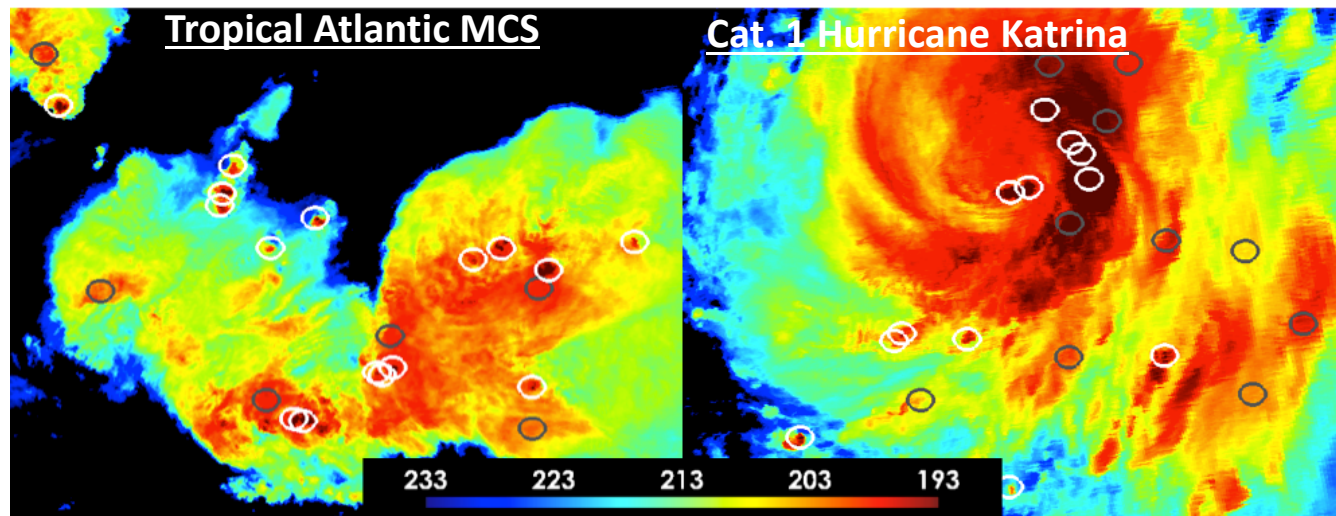
OT Probability  $\geq 0.5$  (Red) Atop Human-Identified OTs (White Circles) and 250 m Visible Imagery





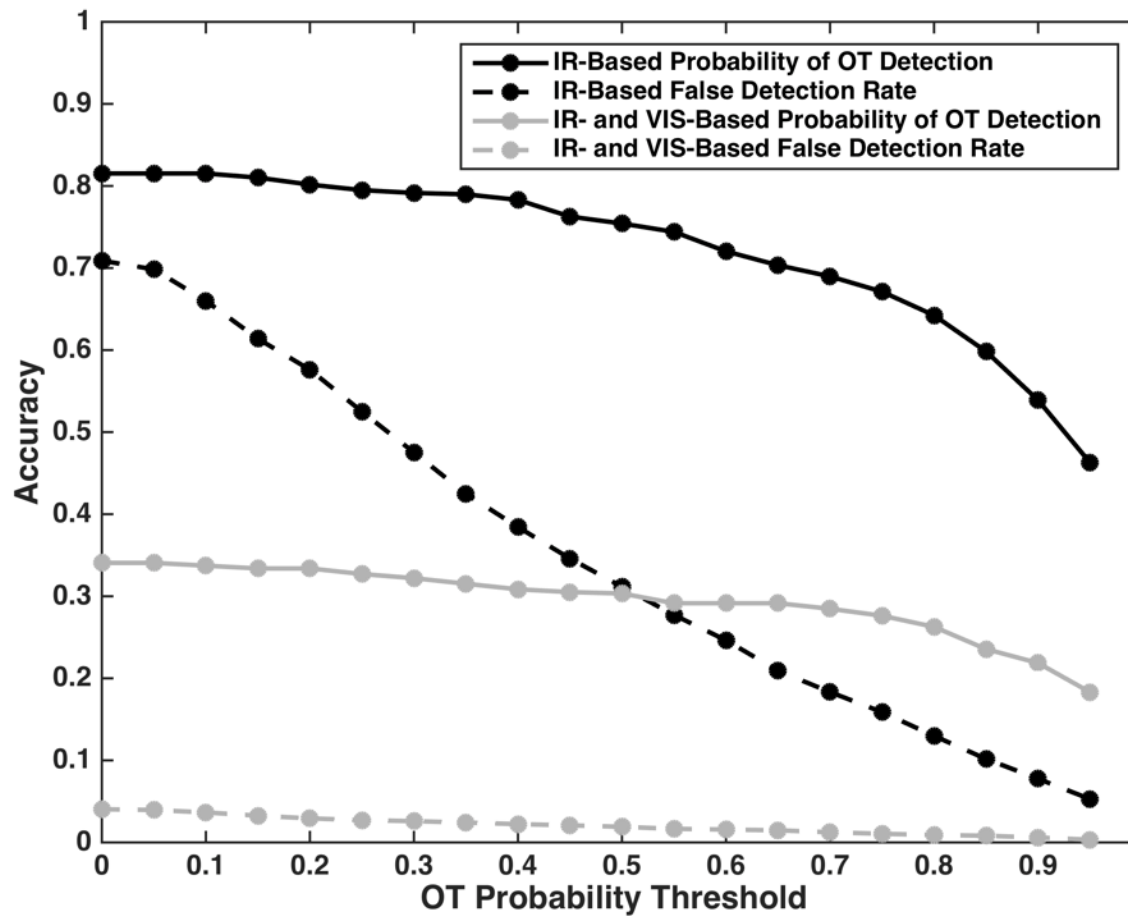
# OT Detection Validation

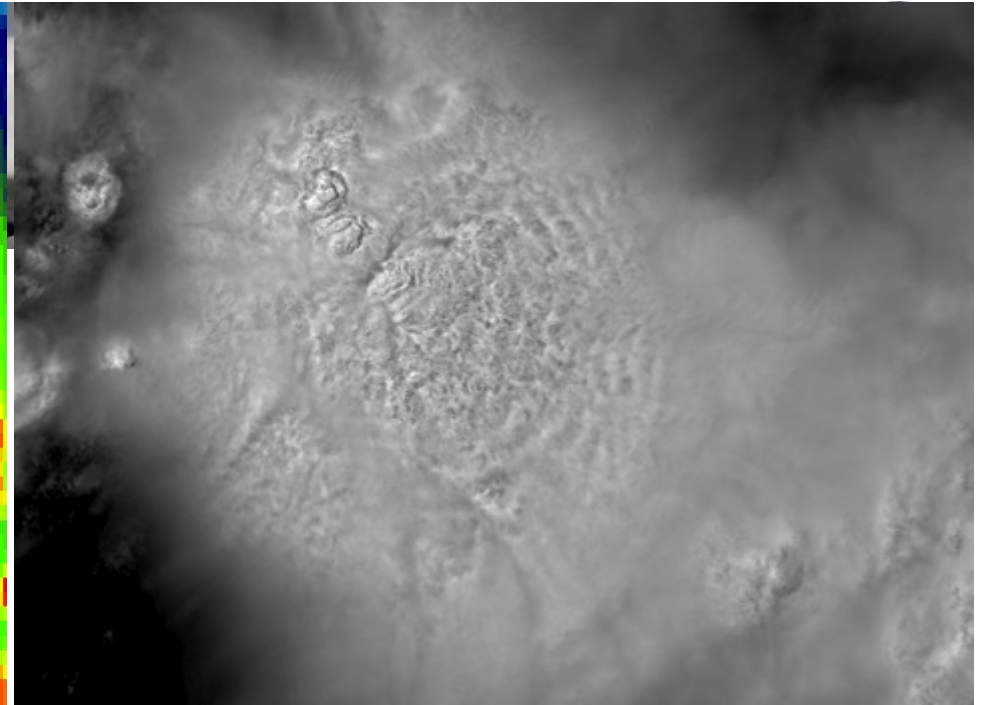
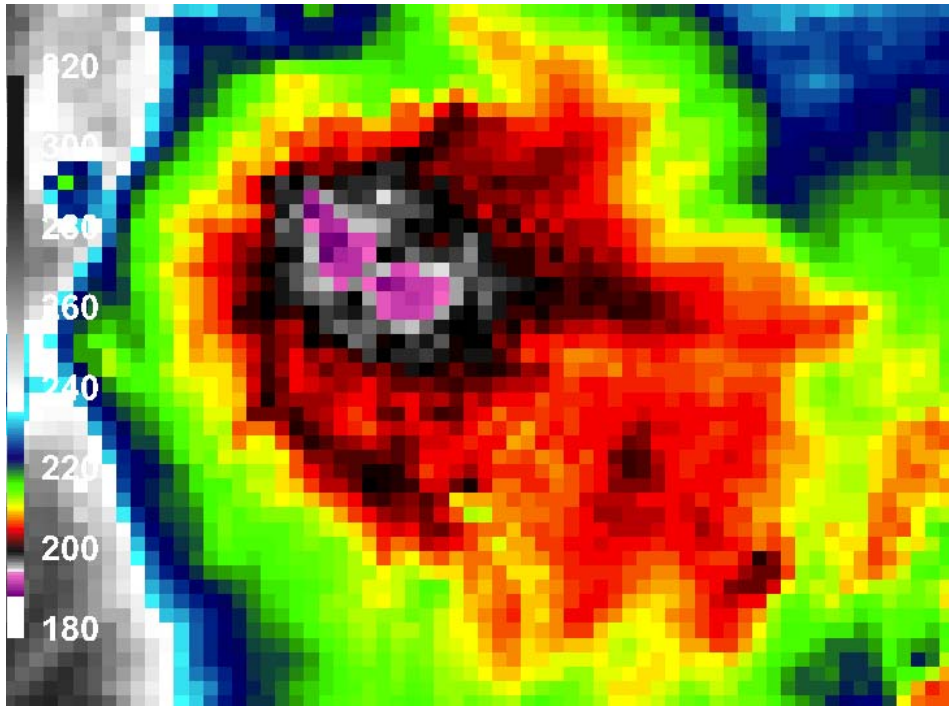
How Well Can The Algorithm Discriminate Between Human-Identified OT Regions (White Circles) and Non-OT Regions (Grey Circles)?



Number of OT Regions 809	Number of Non-OT Regions 615
Number of OT Regions With OT Probability $\geq 0.5$ 593 (41.6%)	Number of Non-OT Regions With OT Probability $\geq 0.5$ 58 (4.1%)
Number OT Regions With OT Probability < 0.5 or Lack of OT Detection 216 (15.2%)	Number of Non-OT Regions With OT Probability < 0.5 or Lack of OT Detection 423 (39.1%)
OT Discrimination Skill: 80.7%	

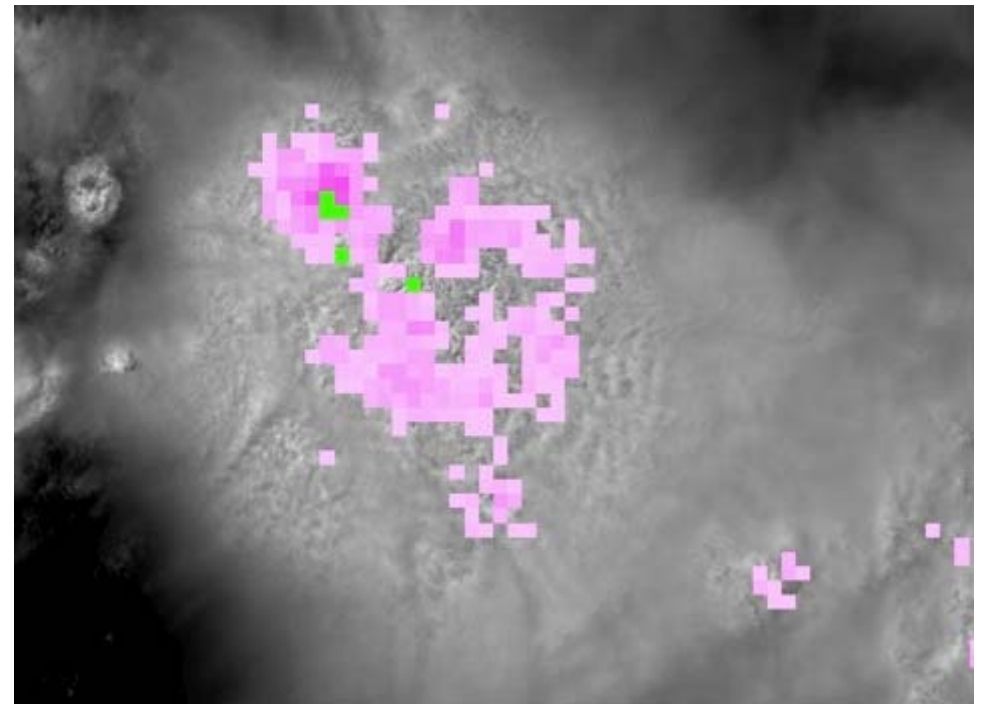
# OT Detection Validation

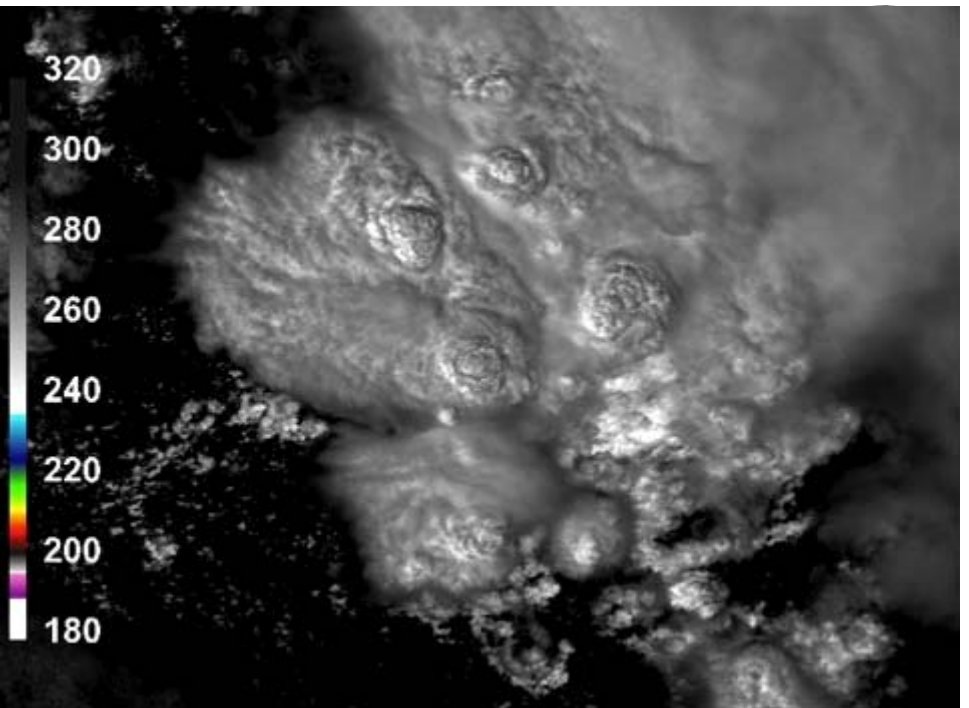
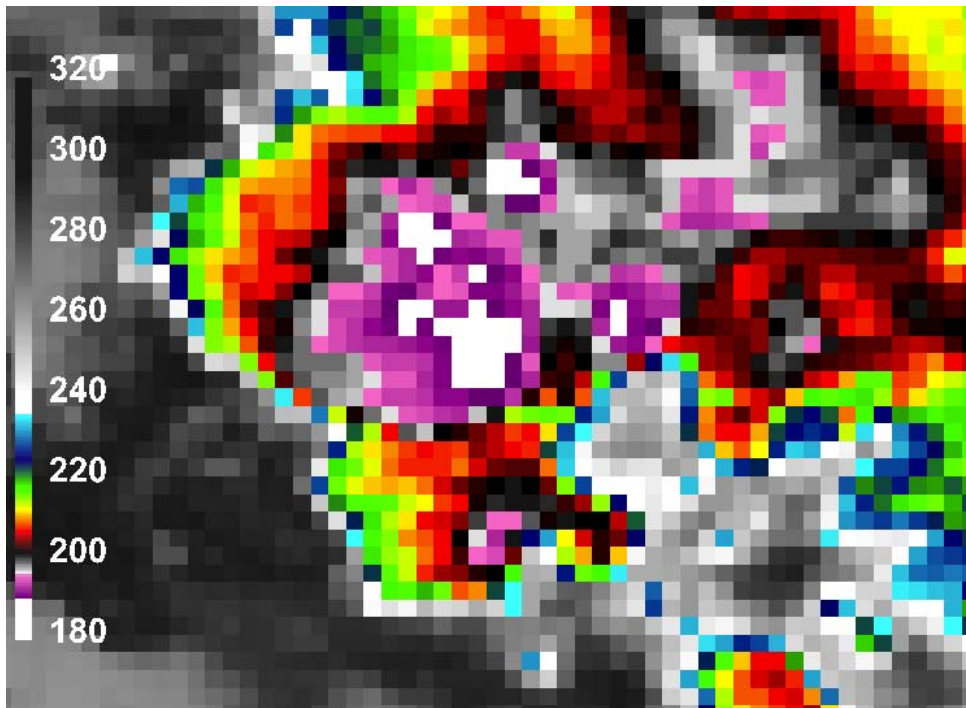




***MODIS Tropical OT  
Detection Example***

***Central Atlantic Ocean  
5 August 2008, 1555 UTC***

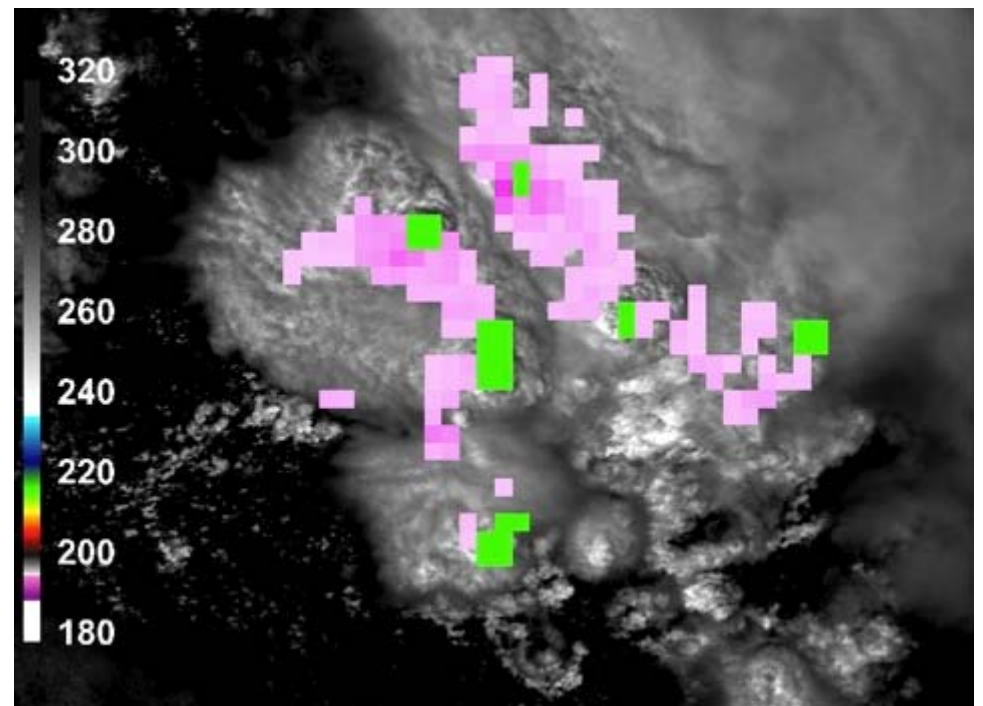




## ***MODIS Tropical OT Detection Example***

***Eastern Congo***

***29 November 2008, 1215 UTC***



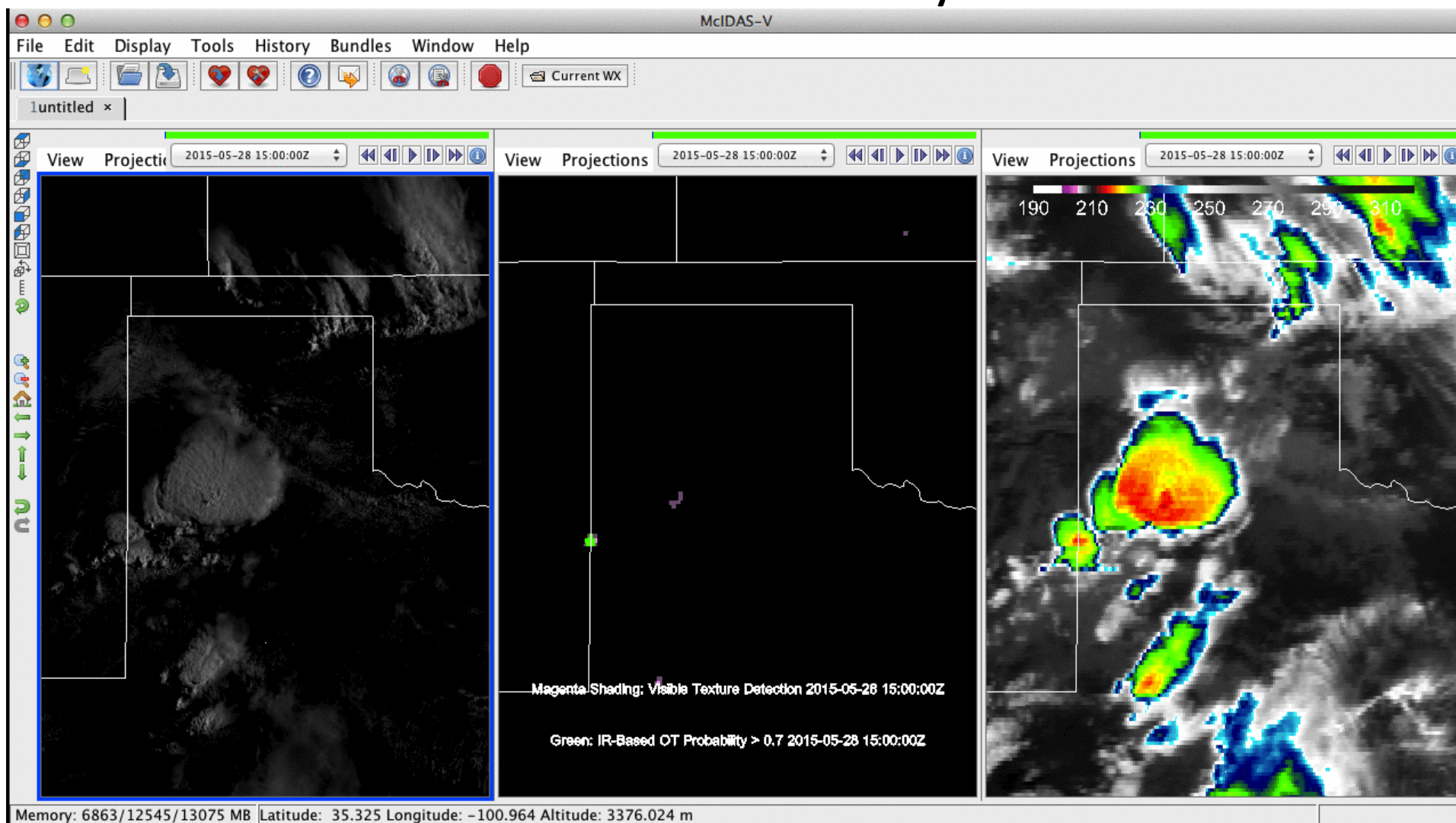


# ***GOES-14 1-Min Imagery***

## ***Severe Storms Over the TX Panhandle: May 28 2015***

**Magenta: Visible Texture Detection**

**Green: IR-Based OT Probability > 0.7**



# UTLS-Penetrating Storm Database over the African Great Lakes Region

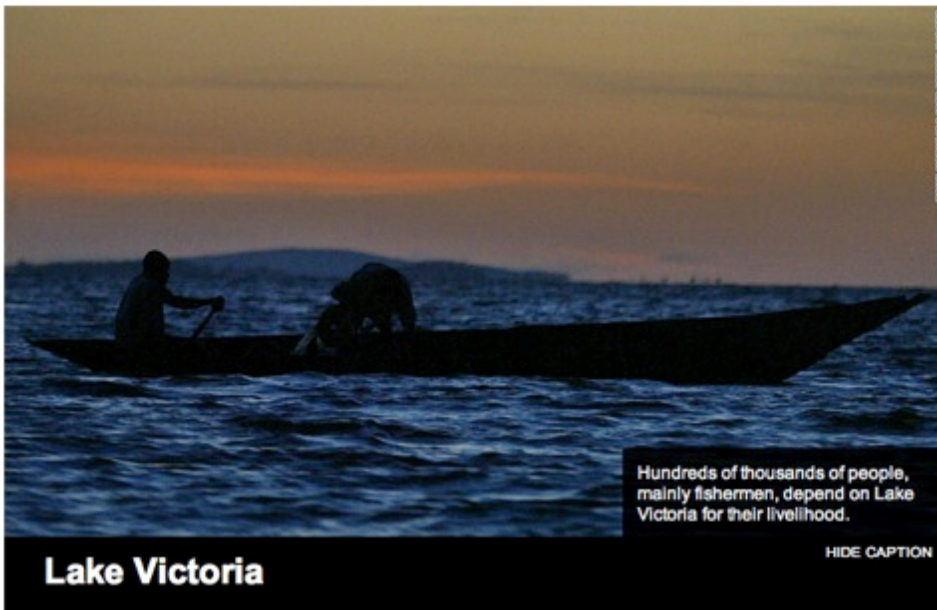


## Lethal weather on 'world's most dangerous lake'

From Errol Barnett, CNN

updated 9:46 AM EST, Thu January 17, 2013

CNN World



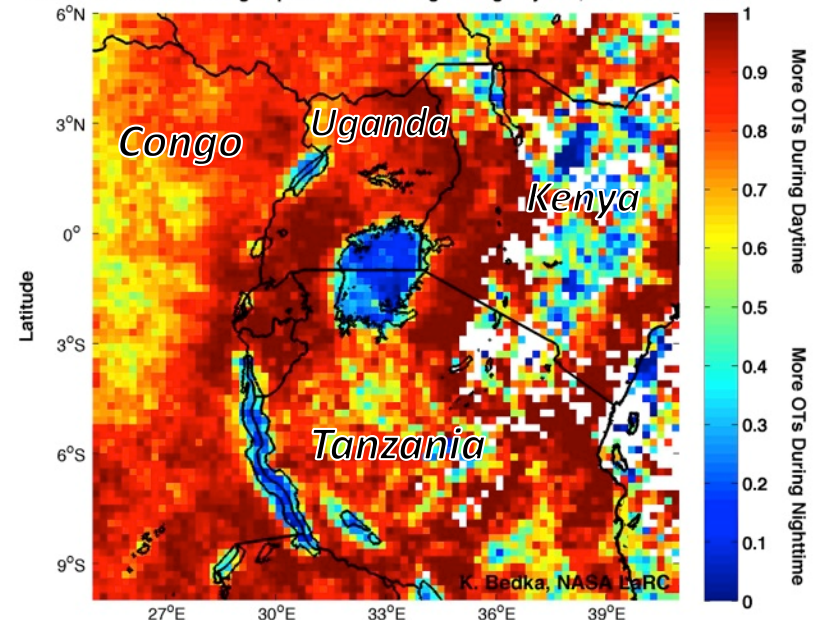
Hundreds of thousands of people, mainly fishermen, depend on Lake Victoria for their livelihood.

Lake Victoria

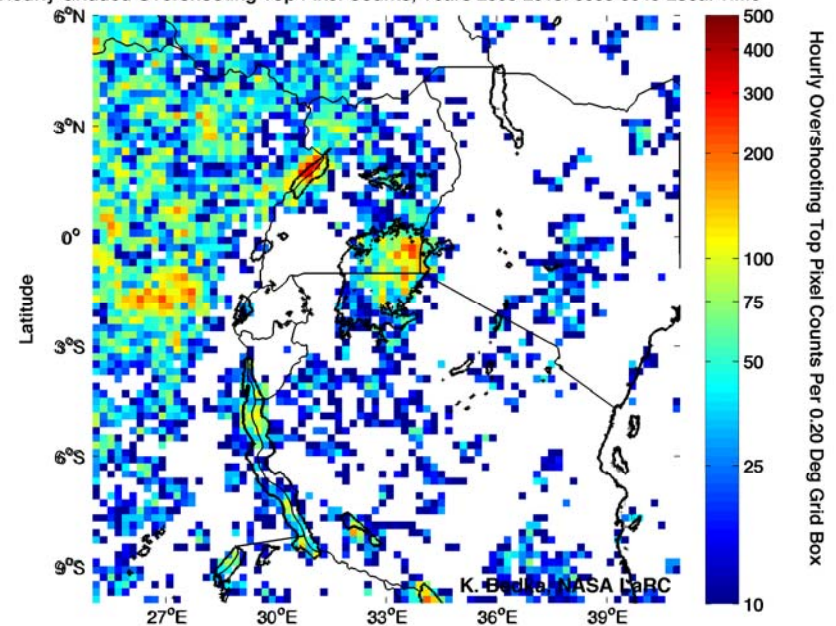
5000+ people are killed on the African Great Lakes every year, most often caused by severe weather

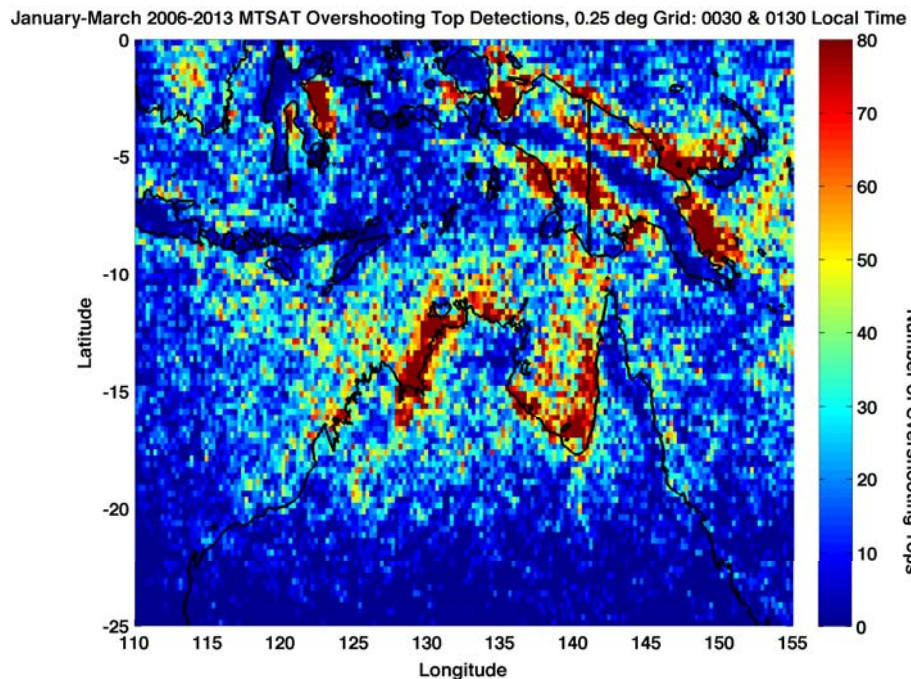
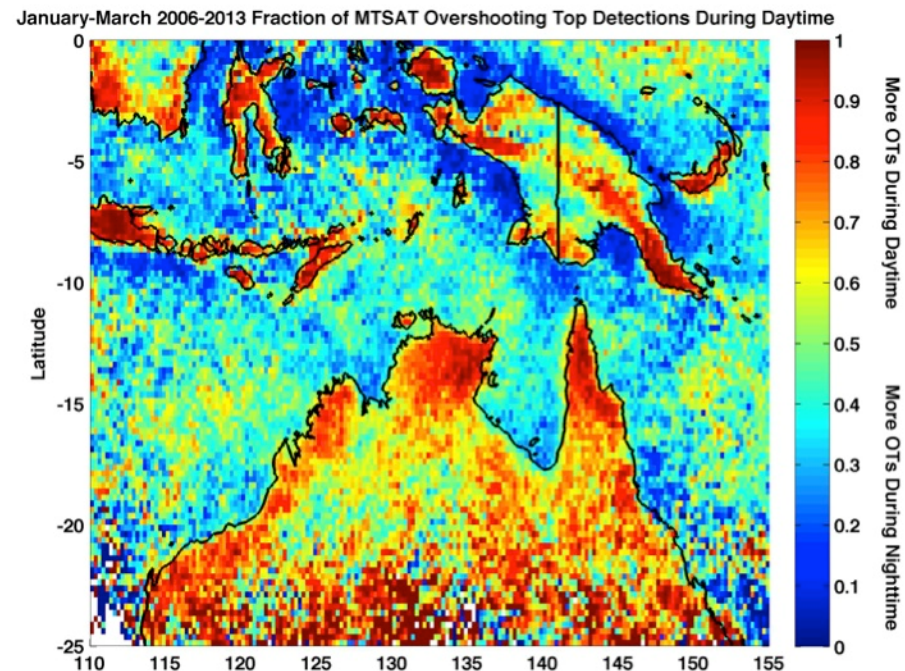
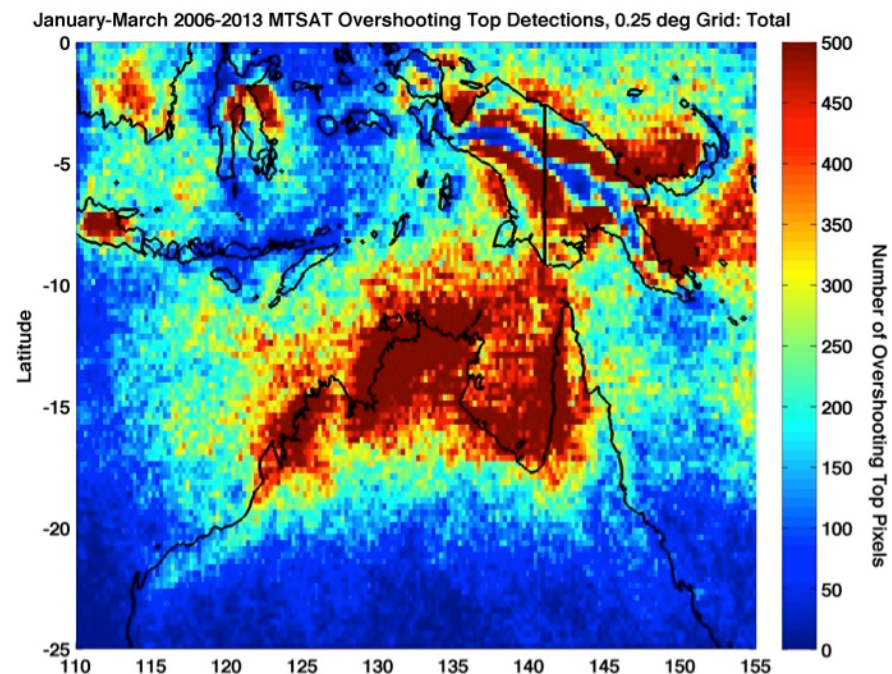
NASA LaRC and international partners are trying to determine the controlling factors for the occurrence of hazardous thunderstorms over the African Great Lakes region via a regional climate model and satellite-based OT detection

Fraction of Overshooting Top Pixels Occurring During Daytime, Years 2005-2013



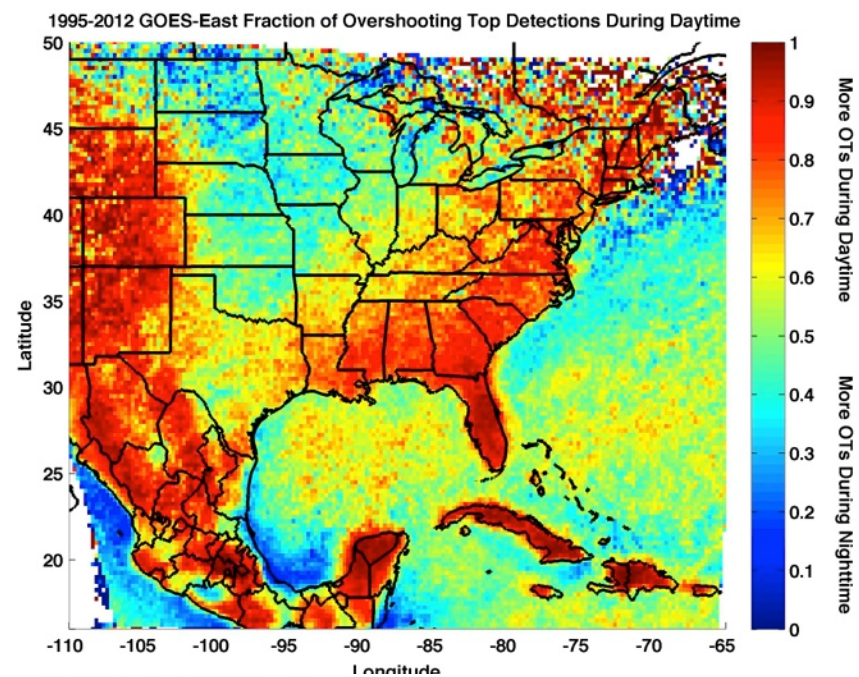
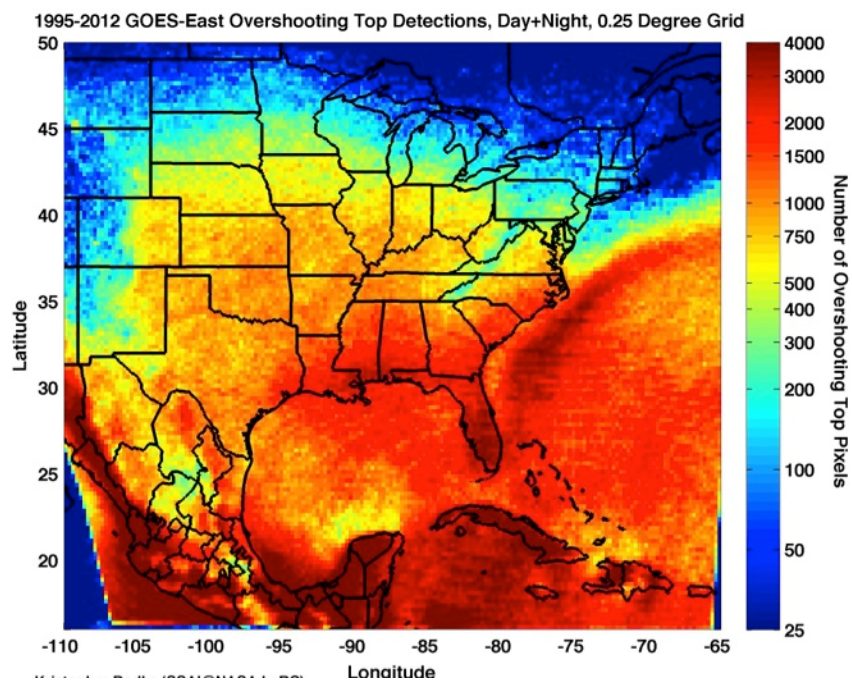
Hourly Gridded Overshooting Top Pixel Counts, Years 2005-2013: 0000-0045 Local Time





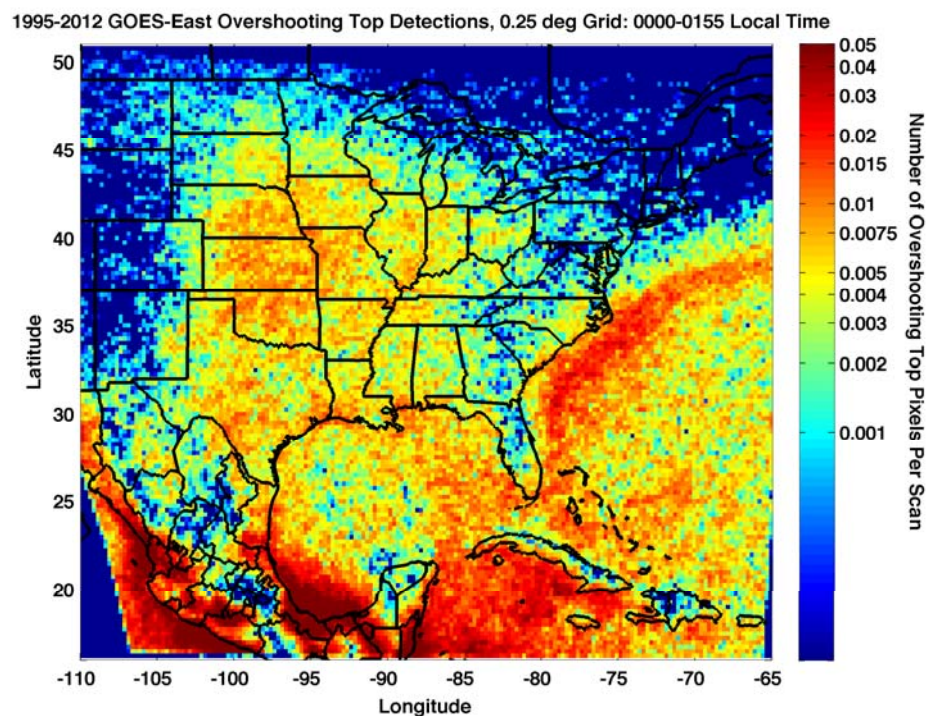
## *UTLS-Penetrating Storm Database over the Maritime Continent and Australia*

- Generated using hourly data from MTSAT, January-March 2006-2013 in preparation for the international HIWC/HAIC field campaign
- Illustrates interesting diurnal variability in storm frequency and distribution



**1995-2012 GOES-East OT Detections Using  
~4 km Spatial Resolution Data  
and Two Images Per Hour**

**OT Detections Assigned To A 0.25 Degree  
Resolution Grid**

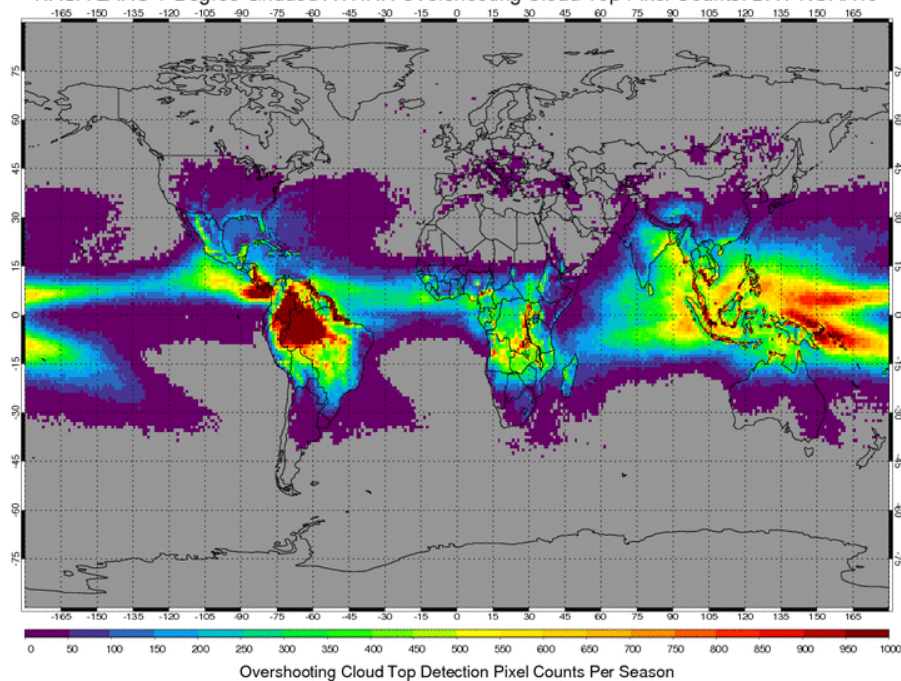


Data Courtesy of  
UW-SSEC Acquired Via McIDAS

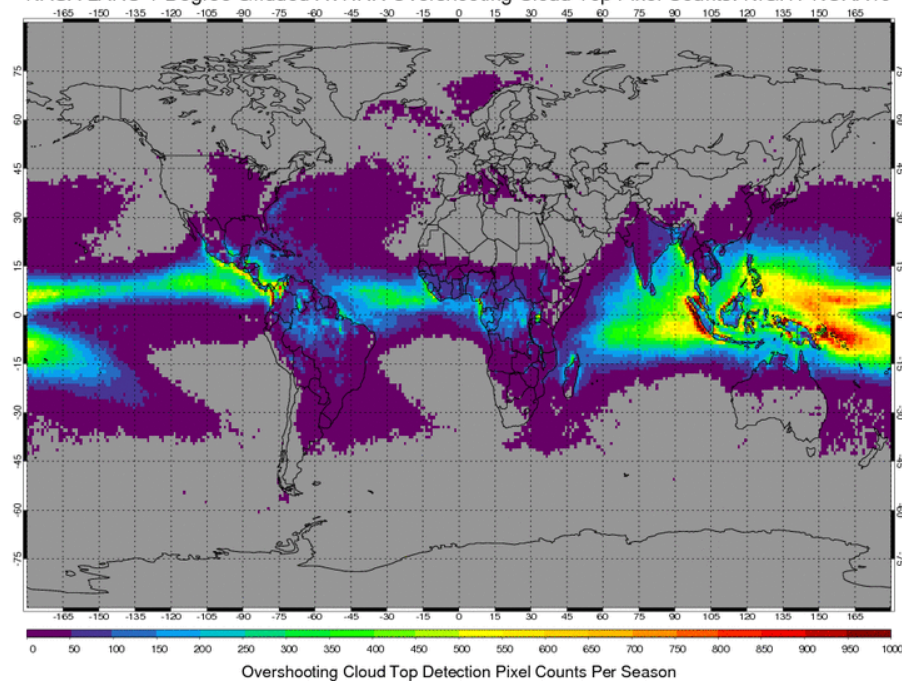
# 20+ Year AVHRR OT Detection Database



NASA LARC 1-Degree Gridded AVHRR Overshooting Cloud Top Pixel Counts: DAY NOAA19



NASA LARC 1-Degree Gridded AVHRR Overshooting Cloud Top Pixel Counts: NIGHT NOAA19



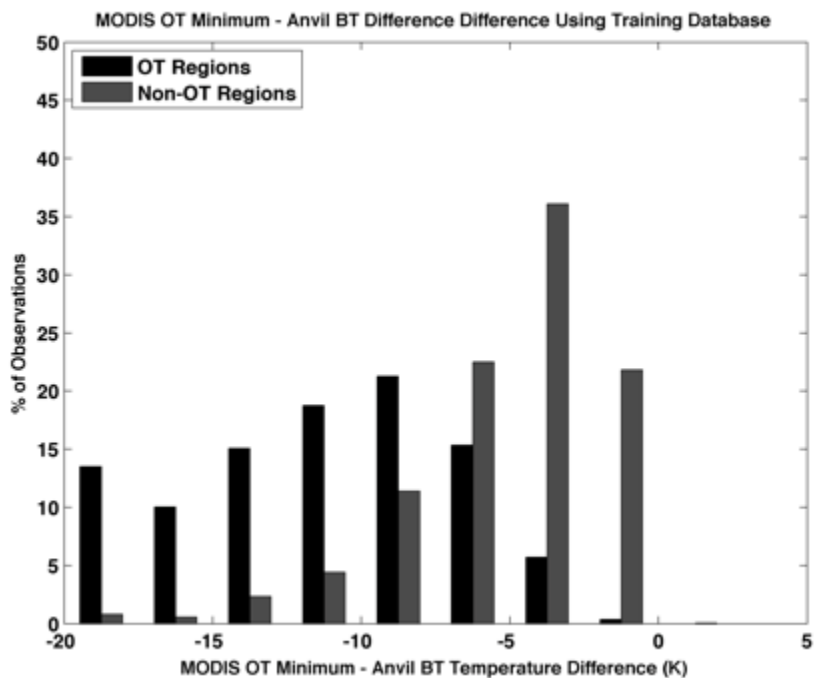




# Summary



- **An automated overshooting cloud top (OT) detection algorithm has been recently improved in support of the GOES-R Advanced Baseline Imager program**
- **The algorithm uses advanced statistical, spatial, and spectral analyses to identify OT signatures at the individual satellite imager (~5 km) pixel scale**
- **An automated OT detection product has been demonstrated or could be used in a number of applications:**
  - 1) Development of a hail risk model for the reinsurance industry (Punge et al. 2014)
  - 2) Analysis of storm distribution throughout the diurnal cycle over the African Great Lakes region (Thiery et al. 2015)
  - 3) Hazardous storm nowcasting by NOAA and within airborne field campaigns (e.g. High Ice Water Content – High Altitude Ice Crystals (HIWC-HAIC), GRIP, and HS3)
  - 4) Analysis of the origin of stratospheric WV plumes during SEAC4RS
  - 5) Validation of weather or climate model predictions of UTLS-penetrating storms
- **The highly efficient nature of the algorithm coupled with immediate access to the entire geostationary image archive from NASA LaRC enables development of a 20+ year OT event climate data record that can be used by the community to derive trends in global UTLS-penetrating storm frequency and distribution**



## *Histograms of OT and Non-OT Regions*

